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The Absorbers Toward CSO 118: Superclustering at z~ 3, or an Intrinsic Absorption Complex?[1]

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ABSTRACT

We present two low resolution ($R \sim 1300$) high signal-to-noise spectra ($W_{\rm r,lim} \approx$ 50 mÅ) of the quasar CSO 118 ($z_{\rm em} = 2.97$) taken with the Hobby–Eberly Telescope Marcario Low Resolution Spectrograph. We detect eight absorbers selected by the C IV $\lambda\lambda 1548, 1550$ absorption doublet in the redshift range $2.23 \lesssim z_{\rm abs} \lesssim 2.97$, seven of which are $z_{\rm abs} \gtrsim 2.68$. In the redshift range covered by the seven $z_{\rm abs} \gtrsim 2.68$ systems, one expects to find two absorbers. We discuss possible explanations for such an excess of absorbers in a small velocity range. Only superclustering at high redshift and absorption due to intrinsic gas are feasibly allowed.

Subject headings: quasars: absorption lines – quasars: individual (CSO 118)

1. Introduction

In recent years, the analysis of QSO-intrinsic narrow absorption lines (NALs) has become a productive enterprise. There are two smoking guns for the identification of intrinsic NALs: (1) time variability of profile shapes and/or equivalent widths; and (2) demonstration that the absorbing structures only partly occult the background source (the QSO central engine). The latter option can only viably be pursued using high resolution and reasonably high signal-to-noise spectra (Barlow & Sargent 1997; Barlow et al. 1997; Hamann et al. 1997a; Ganguly et al. 1999; Srianand & Petitjean 2000). In the former case, we can search for variability in the equivalent width of absorption profiles using low resolution spectra. To that end, we have embarked on a monitering program of the Verón-Cetty & Verón QSOs using the Marcario Low Resolution Spectrograph on

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the Hobby–Eberly Telescope. Finding variability in absorption profile equivalent widths is a step toward systematically identifying truly intrinsic NALs. Follow-up observations at higher resolving power to look for changes in profiles shapes and/or the signature of partial coverage will remove any shadow of a doubt as to an intrinsic origin.

In this letter, we report on a curiosity - the serendipitous discovery of a complex of absorbers that are possibly intrinsic to the radio–quiet quasar CSO 118 ($z_{\rm em} = 2.97$, $V = 17.0$). In §2, we present the spectra of CSO 118 and details of the observations. In §3, we demonstrate that the absorption complex is unlikely to be a random occurrence. Finally, in §4 and §5, we discuss the possible explanations for this complex under the assumptions that the complex is intervening or intrinsic, respectively.

2. Observations

Two spectra were obtained, separated by eight months, with the Hobby-Eberly Telescope (HET) using the Marcario Low Resolution Spectrograph (Hill et al. 1998). We used the 600 line/mm grism and the 1" slit to achieve a resolving power of $R \sim 1300$ or $\Delta v \approx 230$ km s^{-1} resolution. In Table 1, we report the observing dates and the signal-to-noise (per pixel) of the spectra. The spectra were bias subtracted, and flat-fielded using the standard IRAF[2] image reduction packages. Spectra were extracted using the APALL task and wavelength calibrated. Due to the varying aperture size of the HET, we opted not to attempt flux calibration. Also, since the HET is set at a constant zenith angle, the two spectra suffer from the similar amounts of atmospheric absorption. Thus, it was not necessary to correct for differing airmasses. The spectra cover the range $4280 - 7270$ Å. In each spectrum, the ~ 0.5 hr integration time gives a 3σ rest–frame equivalent width limit better than ~ 50 mÅ, which we also report in Table 1. In Fig. 1, we show the two spectra as instrument counts versus wavelength. The emission lines from Ly α, N V, Si IV, and C IV are clearly visible as well as the $2.52 < z_{\rm abs} < 2.97$ Ly α forest absorption blueward of the Ly α emission line. Using the unresolved feature identification method of Schneider et al. (1993) and Churchill et al. (1999), we identified possible C IV doublets where both the stronger transition ($\lambda 1548$) and the corroborating Ly α were detected at a 3σ confidence and the weaker C IV$\lambda 1550$ doublet transition at 1.5σ confidence [see e.g. Ganguly et al. (2001)]. We detect eight C IV–selected absorbers in the redshift range 2.23–2.97, seven of which are within $\Delta z = 0.26$ of the QSO emission redshift. To each doublet, we fit two Gaussians to measure a deblended C IV$\lambda 1548$ equivalent width. We list these in Table 2 for all eight systems over both epochs of observation as well as the doublet ratios ($= W_{\rm r}(1548)/W_{\rm r}(1550)$). In only one case ($z_{\rm abs} = 2.94$ on 4 March 2000) was deblending unsuccessful due to an insufficiently resolved doublet. In Fig. 2, we show the region of the spectra covering the wavelength range 5650–6150 Å. The spectra have been normalized so that the flux

[2]IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

from both the continuum and emission lines (i.e., the total emitted flux indicent on the absorbers) is unity. Overplotted, we show the fits of the double Gaussians to the seven C IV profiles in this wavelength range.

3. Redshift Path Density of Absorbers

Tripp et al. (1996) reported that the redshift path density of C IV absorbers in the redshift range $1.4 < z_{\rm abs} < 2.9$ and down to an equivalent width limit of 30mÅ is $dN/dz = 7.1 \pm 1.7$. The total redshift path searched in the spectrum of CSO 118 is $\Delta z = 0.85$, so we would expect to find 6.0 ± 1.4 in all. The Poisson probability of finding eight systems when six are expected is 10%. However, seven of the absorbers are clustered on the high redshift side of this path. If one divides the path in two, one finds one absorber in the low reshift bin, and seven in the high redshift bin. In each of these bins, the redshift path is $\Delta z = 0.425$ in which one expects to find 3.0 ± 0.7 absorbers on average. The Poisson probabilities of finding one and seven absorbers in the $\Delta z = 0.425$ path are 14 ± 7% and 2 ± 2%, respectively. Finding only one absorber in the low redshift bin is not a statistically significant decrement. However, finding seven in the high redshift bin is a very significant excess. Moreover, if such an absorption complex were common, one would expect the two-point correlation function (TPCF) of C IV–selected systems at $z \sim 3$ to show an above average amplitude at large velocities. Rauch et al. (1996) report that the amplitude of the TPCF falls off to the average value (i.e., uncorrelated distribution of systems in redshift space) beyond 400 km s^{-1}. Therefore, this complex is not only highly significant, but also very rare. We discuss two possible origins for the excess of C IV doublets in the spectrum of CSO 118: (1) absorption from intervening structures; or (2) absorption by gas intrinsic to the QSO.

4. Intervening Absorption

Intervening C IV absorption has traditionally been attributed to galaxy halos (Steidel et al. 1987; Petitjean & Bergeron 1994), high ionization species associated with the Ly α forest (Lu 1991; Songaila & Cowie 1996; Kirkman & Tytler 1999), or hierarchical galaxy formation [Rauch, Haehnelt, & Steinmetz (1997); hereafter RHS]. The hierarchical collapse of H I into sheets and filaments has been shown through many impressive simulations [e.g., Davé et al. (1999); Machacek et al. (2000)] to reproduce the so-called Ly α–forest which is prevalent in the spectra of QSOs blueward of the Ly α emission.

Both galaxy halo absorption and forest absorption (from C IV) are accounted for by standard dN/dz measurements. Thus only the presence of a few absorbers (3.0 ± 0.7 in $\Delta z = 0.425$) can be explained in this manner. In the model of hierarchical galaxy formation, as discussed by RHS, a dense H I filament (see, for example, their Fig. 3) gives rise to low ionization absorption (e.g., H I, C II, Si IV). This is surrounded by a lower density phase (giving a high ionization parameter) that

produces C IV absorption. This lower density phase is encompassed by an even lower density phase that yields very high ionization O VI absorption. A HIRES/Keck spectrum of the $z_{\rm abs} = 2.768$ system [Kirkman & Tytler (1999); hereafter KT] toward CSO 118 shows precisely this type of structure (see their Fig. 1). KT performed a Voigt profile decomposition of the system profiles to extract column densities and Doppler widths for each velocity component of each transition. Noting the differences in the C IV and O VI Doppler widths, KT reported this as evidence of distinct high ionization phases and speculated that this was evidence of a hierarchical merging event.

While the hierarchical galaxy formation scenario may also be responsible for a few absorbers, it is unlikely to explain a whole complex spread over $20,000$ km s^{-1} as seen along the CSO 118 line of sight. Regardless of whether or not the absorption is intrinsic or intervening, the seven $2.68 < z_{\rm abs} < 2.94$ absorption systems must arise from structures that are somehow correlated. Another possibility related to the RHS scenario is the fragmentation of a large H I filament to from several "protogalactic clumps" (PGCs), that is, the formation of a cluster of galaxies or a supercluster. The seven absorbing systems are spread over $20,000$ km s^{-1}. Moreover, rich clusters of galaxies typically have velocity dispersions of ~ 1000 km s^{-1}; it is rare, indeed, to find clusters with dispersions as large as 2000 km s^{-1} – an order of magnitude smaller than what is required here. The only viable explanation invoking intervening absorption is superclustering.

Superclustering involves the clustering the galaxy clusters. Several superclusters have been identified in the last couple decades like the Great Wall (de Lapparent et al. 1988, 1991) from the CfA redshift surveys (which includes the Coma cluster), the Perseus–Pisces supercluster (Gregory et al. 1981), the Hercules supercluster (Tarenghi et al. 1979; Chincarini et al. 1981; Gregory & Thompson 1984), and the Local Supercluster (Yahil et al. 1980; Tully 1982; Huchra et al. 1983). The bulk of these low redshift superclusters are dominated by rich clusters like those in the Abell (1958) and Abell et al. (1989) catalogs. In instances where the filamentary structure seen in these superclusters is aligned with the line of sight such as in the Aquarius supercluster (Batuski et al. 1999), the velocity distribution of clusters can reach $1 - 2 \times 10^4$ km s^{-1}. At high redshift, if the corresponding "protocluster" clumps (PCCs) provide C IV absorption in the spectrum of a background QSO, this could explain the complex of absorption seen in the CSO 118 line of sight. It is not difficult to imagine an H I filament that is fragmenting into PCCs with a QSO behind it. The extragalactic background, dominated at high redshift by the ultraviolet and reprocessed soft X–ray emission from AGN (Haardt & Madau 1996), ionizes the PCCs. The ionization structure of each of these PCCs would be similar to that described by RHS and KT, with multiple phases of low density, high ionization gas surrounding higher density, lower ionization gas.

Superclustering is not a new idea in the realm of quasar absorption lines. There have been several reports in the literature of binary QSOs in which absorption at common redshifts occur. The most famous of these is the "Tololo pair," Tol $1037 - 2704$ and Tol $1038 - 2712$ (Bohuski & Weedman 1979; Jakobsen et al. 1986), where the candidate supercluster is at $z \sim 2$. Other reports include UM 680/681, and Q $2343+125$/Q $2344+125$ (Sargent 1988) [see also Romani et al. (1991); Francis & Hewett (1993); Williger et al. (1996); Francis et al. (1996); Williger et al. (2000)]. These

claims are usually based on the coincidence of absorbers in redshift (implying gas that is possibly in common to both lines of sight) and the separation of the QSOs (17' in the case of the Tololo pair implying a *minimum* size of $\sim 4\mathrm{h}^{-1}$ Mpc). However, these claims are still controversial as it is still unknown whether they caused by intervening structures or whether they arise due to the presence of a relativistic outflow from the QSO central engine (see §5). We note here that there are no bright extragalactic objects (for which to do absorption line spectroscopy) in the NASA/IPAC Extragalactic Database at high redshift within 20' of CSO 118. Thus, a study of the transverse extent of this structure (if it is intervening) is unlikely. There is, at least, one other object in the literature, Q 2359+068, with a similar concentration of absorbers (8 in the range $2.73 < z_{\mathrm{abs}} < z_{\mathrm{em}}$, with a Poisson probability of $1 \pm 1\%$).

5. Intrinsic Absorption

The complex of high redshift absorbers toward CSO 118 can also plausibly be of an intrinsic origin. First, intrinsic NALs have been detected at high ejection velocities up to $v_{\mathrm{ej}} \sim 56000$ km/s (Jannuzi et al. 1996; Hamann et al. 1997b; Richards et al. 1999). Second, multiple (2–3) intrinsic absorption systems are also observed – e.g., PG $2302+029$ (Jannuzi et al. 1996), PG 0935+417 (Hamann et al. 1997c), Q $0835+5803$ (Aldcroft et al. 1997). Furthermore, at low redshift, there is an enhanced probability of a radio–quiet QSO hosting an intrinsic NAL when one detects broad absorption (a BAL) (Ganguly et al. 2001). Thus, it is reasonable to expect multiple absorption systems that are intrinsic to a given QSO.

Unfortunately, on the two month rest–frame timescale over which the CSO 118 was observed, neither the equivalent width, nor the doublet ratio of any profile varied. (Also, since the features are unresolved, it make little sense to compute coverage fractions.) Either evidence for time variability or partial coverage would provide a smoking gun for an intrinsic origin. Nevertheless, it must be noted that the *lack* of variability of the profiles does not preclude an intrinsic origin. Moreover, because the profiles are unresolved, we would not have detected changes in the profile shapes. We offer two possible scenarios to explain this absorption complex under the accretion-disk/wind model (Murray et al. 1995; Proga et al. 2000). The first scenario involves the presence or the development of a BAL outflow, while the second proposes periodic or stochastic mass loss events.

In the accretion-disk/wind model for the QSO central engine, matter orbits a supermassive black hole in a geometrically thin, optically thick disk and spirals inward as a result of viscous friction. Matter on the surface of the disk is lifted via radiation pressure. The rate at which this matter is lost is regulated by the balance between the mass accretion rate, which is capped by the Eddington rate, and the mass fueling rate. As this mass is blown off the disk, it is blindsided by an even more powerful force: radiation pressure from the inner part of the disk which radiates a UV/soft X–ray continuum. This results in a relativistically and radially accelerated wind blowing away from the disk. However, the matter leaving the disk retains its angular momentum. So as it is radially accelerated, it spirals away from the disk in a helix. This rotational component can

play an important part in the projected line-of-sight velocity of the wind and, by consequence, the optical thickness to photons emitted by the accretion disk and broad line region. The broad UV emission lines originate from the lower regions of the wind where the matter is optically thick.

The complex of absorption seen toward CSO 118 may be connected to BAL-type outflow. In the accretion-disk/wind model described above, BAL outflow is understood to occur when the mass fueling rate greatly exceeds the mass accretion rate. In this case, the wind becomes optically thick and photons attempting to pass through the wind are completely absorbed. Moreover, since there is a large velocity gradient in the wind, the absorption, as well, occurs over a broad range in velocities. Thus, all radio–quiet QSOs are viewed as *having* a BAL outflow, but in only $\sim 10\%$ of such cases are the viewing angle and wind opening angle such that a BAL is seen. CSO 118 fits in nicely with being like a BALQSO in which the line(s) of sight graze the BAL outflow. The absorbers span ejection velocities up to $23,000$ km s^{-1}, reminiscent of typical BAL velocity widths. Like many BALQSOs, CSO 118 is very radio–quiet (a non-detection by the FIRST survey makes the radio–loudness parameter $\log R < 0$). It is also not detected by the ROSAT All Sky Survey (although this merely provides the unrestrictive limit of $\alpha_{\rm ox} \lesssim -1.3$). One possible explanation for the difference between the series of NALs in CSO 118 and a BAL is that the line of sight to the latter grazes clumpy outcroppings of the wind; these clumps, which are cause by Kelvin–Helmholtz instabilities, are seen in the simulations of Proga et al. (2000). According to the simulations, these clumps last on the order of a few years in the QSO rest–frame. A related possibility is that the outflowing wind is starting to become much denser, possibly as a result of a changeins mass fueling/loss rate. It is possible that we are seeing the initial fragmentation of the wind into BAL clouds.

Another possible explanation for CSO 118 is sporadic (or quasi–periodic) mass ejection by the accretion disk. Because the mass accretion rate is capped by the Eddington limit, changes in the mass fueling rate are directly transposed to changes in the mass loss rate. If the fueling rate were to drastically change either periodically or sporadically, the outflowing wind would have a density structure, which can be viewed as a perturbations on the general density law of the wind. The perturbations resulting from an increase in the mass fueling rate would resemble expanding shells. The observational signature of outflowing shells could be complexes of absorbers as seen in the CSO 118 line of sight.

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Table 1. Journal of Observations of CSO 118

Observation Date	Exposure Time	S/N	3σ W_r limit mÅ
03/04/2000	1800s	70	36
11/21/2000	600s		
11/24/2000	900s	55[a]	45[a]
11/25/2000	900s		

[a]The three integrations taken in November 2000 were co-averaged to give the reported S/N and 3σ W_r limit. The smaller S/N in the November spectrum resulted primarily from poorer seeing conditions.

Table 2. Equivalent Widths of C IV doublets

	03/04/2000			11/24/2000		
z_{abs}	Wavelength Å	$W(1548)$ Å	D.R.	Wavelength Å	$W(1548)$ Å	D.R.
2.244	5022.4 ± 0.2	0.59 ± 0.06	0.9 ± 0.1	5021.6 ± 0.3	0.67 ± 0.08	1.5 ± 0.3
2.678	5694.2 ± 0.2	0.63 ± 0.06	1.8 ± 0.3	5694.5 ± 0.3	0.71 ± 0.07	1.3 ± 0.4
2.705	5737.6 ± 0.4	0.31 ± 0.06	1.3 ± 0.4	5737.9 ± 0.5	0.42 ± 0.07	1.5 ± 1.0
2.744	5796.6 ± 0.3	0.56 ± 0.07	1.8 ± 0.4	5797.0 ± 0.4	0.67 ± 0.08	2.1 ± 0.8
2.769	5835.1 ± 0.1	1.80 ± 0.08	1.7 ± 0.1	5834.3 ± 0.2	1.74 ± 0.09	1.1 ± 0.2
2.841	5946.9 ± 0.5	0.41 ± 0.08	1.8 ± 0.6	5945.0 ± 1.0	0.48 ± 0.10	1.8 ± 0.9
2.874	5998.2 ± 0.2	0.63 ± 0.06	1.8 ± 0.4	5997.5 ± 0.5	0.58 ± 0.08	1.5 ± 0.6
2.940	6100.1 ± 1.9	0.89 ± 0.14[a]	...	6096.8 ± 0.7	0.34 ± 0.07	1.0 ± 0.5

[a]The C IV doublet profile could not be deblended. The listed equivalent width is of the blended feature.

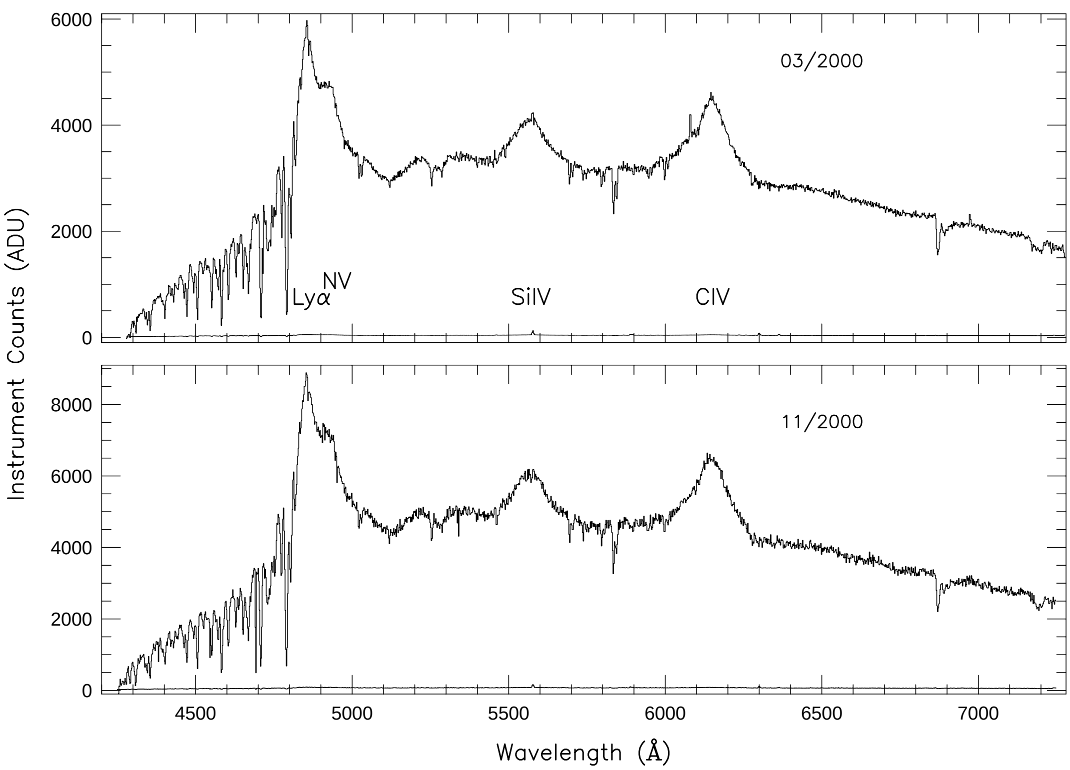

Fig. 1.— Spectra of CSO 118 taken at two epochs (March and November 2000) with the Marcario Low Resolution Spectrograph (Hill et al. 1998). The spectra cover the Lyα, N V, Si IV, and C IV emission lines, and part of the Lyα forest. The spectra have not been flux calibrated or corrected for atmospheric absorption, since HET is set at a constant airmass ($\sec z = 1.1 - 1.3$). We detect one C IV–selected absorption system on the red wing of the N V emission and seven between the Si IV and C IV emission lines.

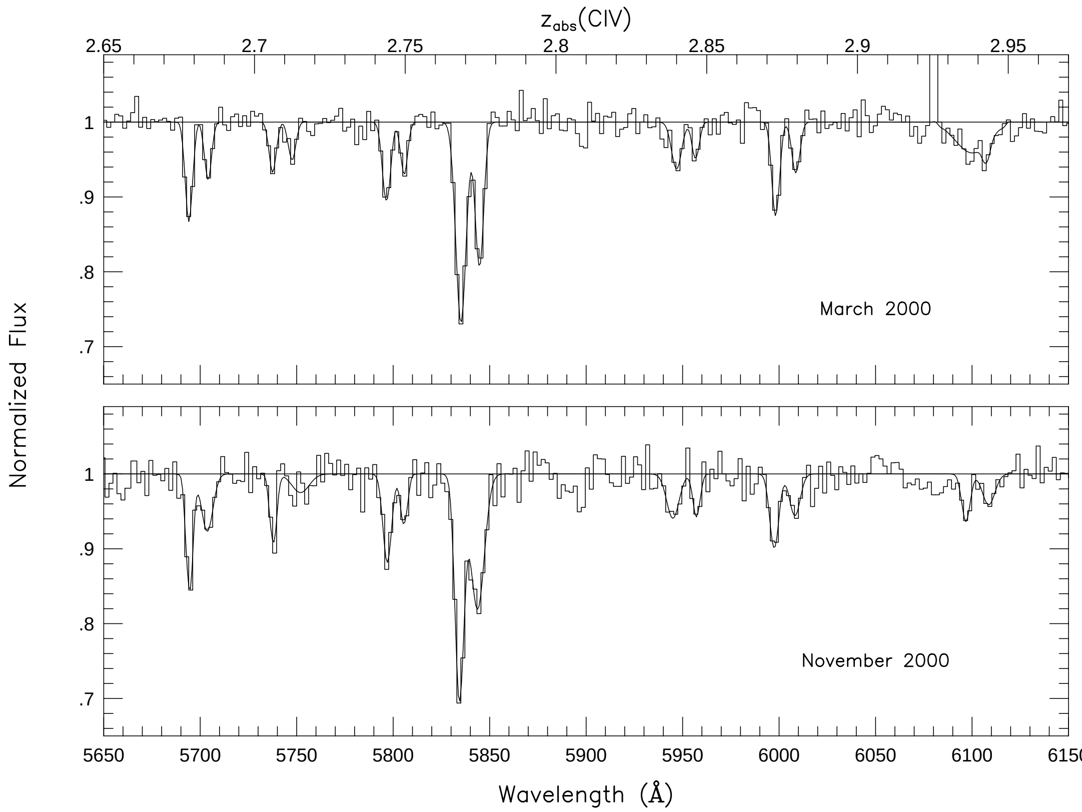

Fig. 2.— A "zoomed" in region, from 5650–6150 Å, of the spectra of CSO 118. Overlayed on the data are the double Gaussian fits to the each of the C IV doublet profiles. On the top axis, we show the redshift of the C IV $\lambda1548$ line. This part of the spectrum shows the seven C IV–selected absorbers in the redshift range $z_{\rm abs} = 2.68 - 2.94$. The equivalent widths and doublet ratios of the profiles did not change during this rest–frame two month period.